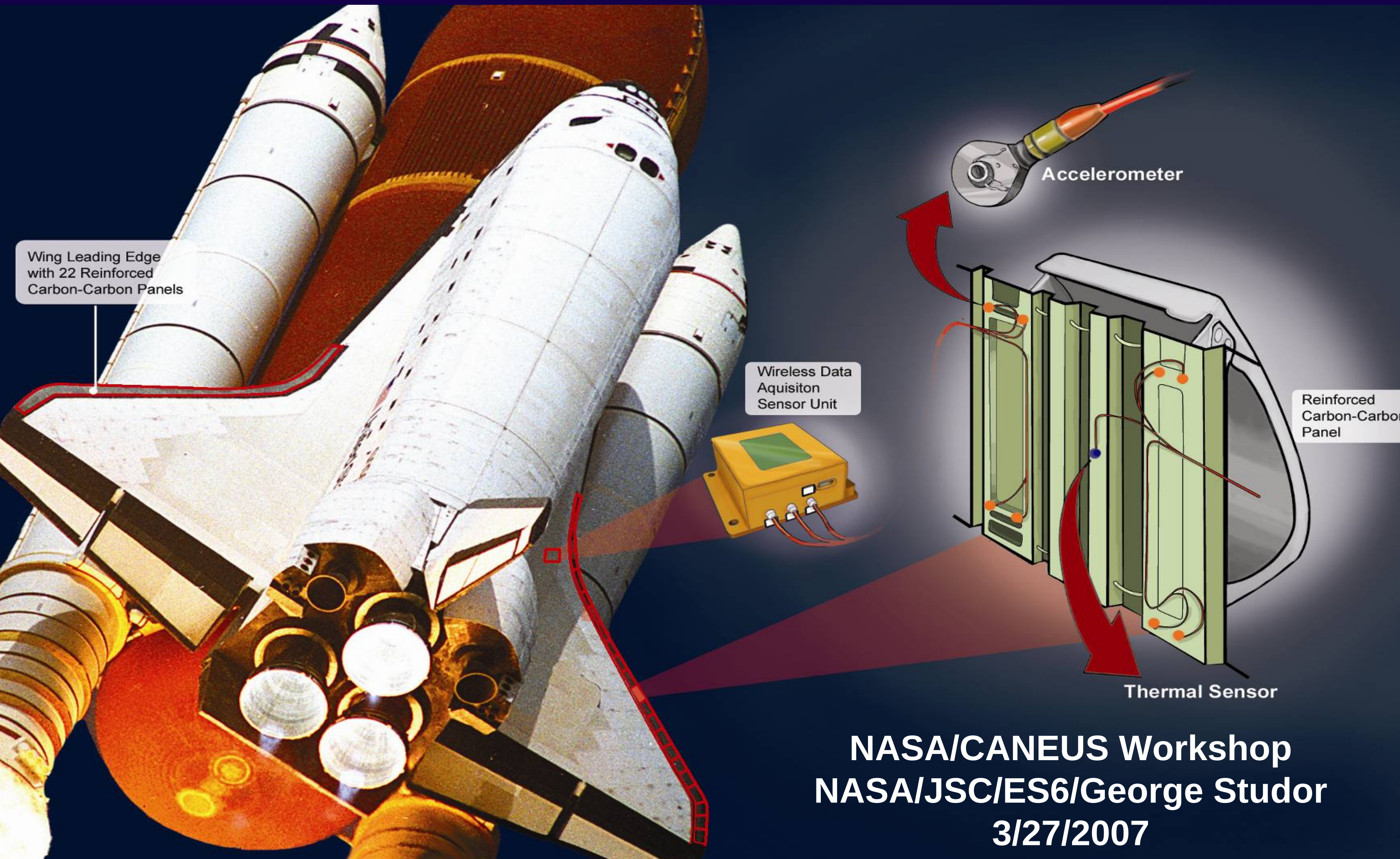
“Fly-by-Wireless” : A Revolution in Aerospace Architectures for Instrumentation and Control



NASA/CANEUS Workshop
NASA/JSC/ES6/George Studor
3/27/2007

“Fly-by-Wireless”

(What is it?)

Vision:

To minimize cables and connectors and increase functionality across the aerospace industry by providing reliable, lower cost, modular, and higher performance alternatives for a vehicle/program's life-cycle.

Why are we holding this workshop?

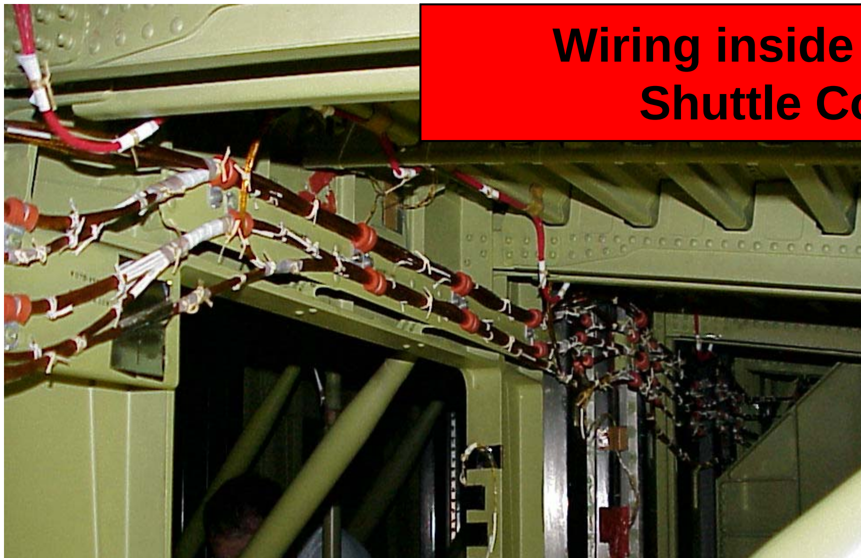
1. **Increasing the maturity of the wireless state-of-the-art can help NASA’s Exploration Programs and other flight and ground test programs.**

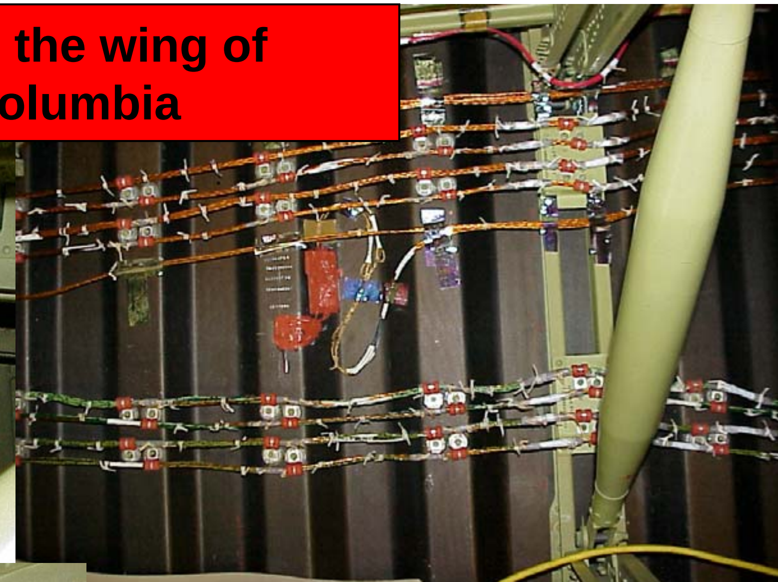
2. **NASA research and flight experience can help accelerate the aerospace industry state-of-the art.**

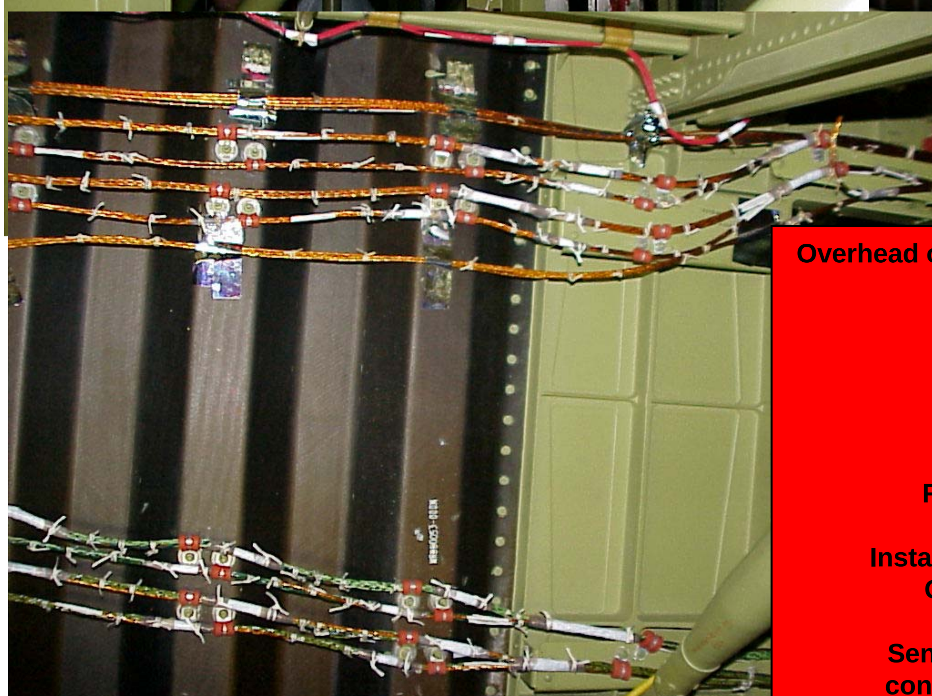
3. **Partnerships developed in this common objective can lead to new innovations and applications we haven’t thought of yet.**

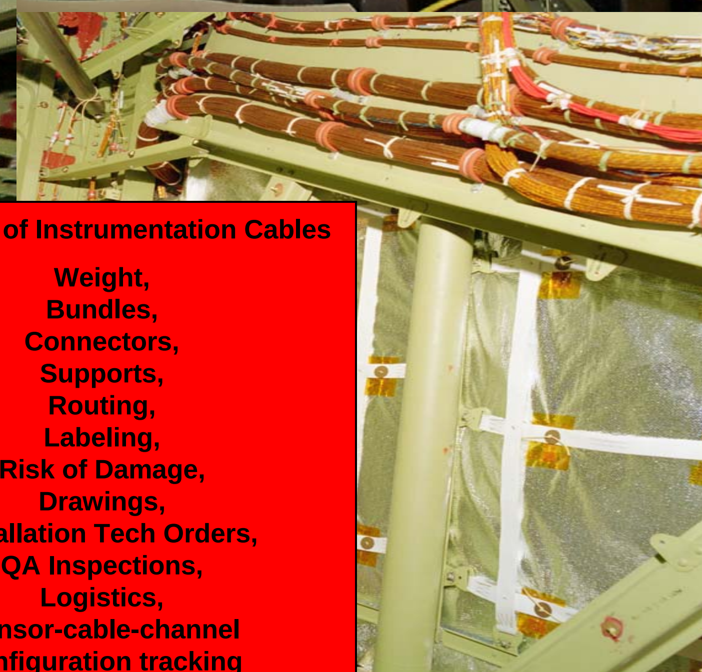
4. **A longer term international effort to reduce wires and connectors across the industry and around the world has shown to be of considerable interest.**

Wiring inside the wing of Shuttle Columbia









Overhead of Instrumentation Cables

Weight,
Bundles,
Connectors,
Supports,
Routing,
Labeling,
Risk of Damage,
Drawings,
Installation Tech Orders,
QA Inspections,
Logistics,
Sensor-cable-channel configuration tracking

CANEUS "Fly-by-Wireless" Project Goals

- **Establish an international forum through the CANEUS Organization to exchange public and published information on wireless alternatives and new innovations which precipitate cooperation and partnerships between industry/government customers, system innovators and technology developers.**

- **Promote understanding of the maturity and capability of alternatives to wired infrastructure,**

- **Identify solution paths for key challenges, such as FAA regulations, certification requirements, RF/EMI/EMC, structural design/access & spectrum management.**

- **Quantify the life cycle return on investment or mission need for various applications and opportunities to establish which investments and partnerships have promise.**

- **Identify and enable key partnerships to make progress in implementing "Fly-by-Wireless" in aerospace vehicles.**

CANEUS “Fly-by-Wireless” Workshop Objectives

- **Communicate the CANEUS “Fly-by-Wireless” Vision and concept for Project Partnering.**
- **Understand the potential Aerospace Applications/End-User Needs and the state-of-the-art in applicable Technology Development.**
- **Develop cooperating Application/End User and Technology Provider associations that intend to further the "Fly-by-Wireless" vision.**
- **Provide communication of results and additional opportunities for further development of cooperative work and partnerships.**

“Fly-by-Wireless” – It’s NOT just about Weight or Wireless Flight Control

- **Expenses for Cabled Connectivity** begin in Preliminary Design Phase and continue for the entire life cycle.
- **Reducing the quantity and complexity** of the physical interconnects has a payback in many areas.

1. **Failures of wires, connectors** and the safety and hazard provisions in avionics and vehicle design to control or mitigate the potential failures.
2. **Direct Costs**: Measurement justification, design and implementation, structural provisions, inspection, test, retest after avionics r&r, logistics, vendor availability, etc.
3. **Cost of Data not obtained:** Performance, analyses, safety, operations restrictions, environments and model validations, system modifications and upgrades, troubleshooting, end of life certification and extension.
4. **Cost of Vehicle Resources:** needed to accommodate the connectivity or lack of measurements that come in the form of weight, volume, power, etc.
5. **Reliability Design Limitations**: avionics boxes must build in high reliability to “make up for” low reliability cables, connectors, and sensors. Every sensor can talk to every data acquisition box, and every data acquisition box can talk to every relay box….

"Fly-by-Wireless" – It's NOT just about Weight or Wireless Flight Control

6. **Physical Restrictions:** Cabled connectivity doesn't work for monitoring: structural barriers limit physical access and vehicle resources, the assembly of un-powered vehicle pieces (like the ISS), during deployments (like a solar array, cargo/payloads, or inflatable habitat), crew members, robotic operations, proximity monitoring at launch, landing or mission operations.

7. **Performance**: Weight is not just the weight of the cables, it is insulation, bundles, brackets, connectors, bulkheads, cable trays, structural attachment and reinforcement, and of course the resulting impact on payloads/operations. Upgrading various systems is more difficult with cabled systems.

8. **Flexibility of Design:** Cabling connectivity has little design flexibility, you either run a cable or you don't get the connection. Robustness of wireless interconnects can match the need for functionality and level of criticality or hazard control appropriate for each application, including the provisions in structural design and use of materials.

9. **Cost of Change**: This cost grows enormously for as each flight grows closer, as the infrastructure grows more entrenched, as more flights are "lined-up" the cost of delays due to trouble-shooting and re-wiring cabling issues is huge.

Cost of Change for Instrumentation

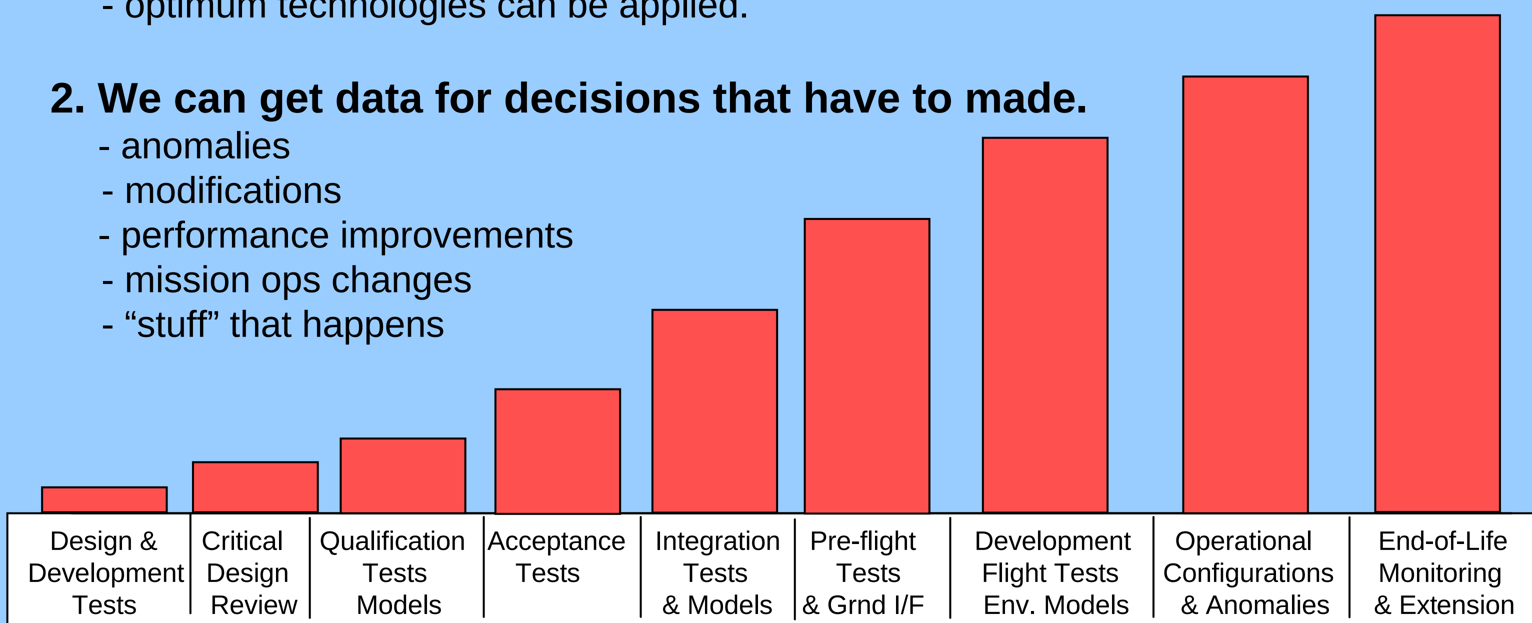
The earlier conventional instrumentation is fixed, the greater the cost of change.

- Different phases uncover and/or need to uncover new data and needs for change.
- Avionics and parts today go obsolete quickly - limited supportability, means big sustaining costs.
- The greater number of integration and resources that are involved, the greater the cost of change.
- Without developed/test systems and environments, many costly decisions result.

We need to design in modularity and accessibility so that:

1. We can put off some decisions until:
- sufficient design, tests/analysis can be made.
- optimum technologies can be applied.

2. We can get data for decisions that have to made.
- anomalies
- modifications
- performance improvements
- mission ops changes
- “stuff” that happens



“Fly-by-Wireless” Reliability

Vehicle Reliability Analyses must include: the End to End system, including man-in-the-loop operations, and the ability to do effective troubleshooting, corrective action and recurrence control.

With Wireless Interconnects, the overall Vehicle Reliability is Increased:

Through Redundancy: All controllers, sensors, actuators, data storage and processing devices can be linked with great redundancy.

Through Structural and System Simplicity: Greatly reduced cables/connectors that get broken in maintenance, must be trouble-shot electronics problems, sources of noisy data and require structural penetrations and supports.

Through Less Hardware: Fewer Cables/Connectors to keep up with

Through Modular Standalone Robust Wireless Measurement Systems: These can be better focused on the system needs and replaced/upgraded/reconfigured easily to newer and better technologies.

Through Vehicle Life-Cycle Efficiency: Critical and non-critical sensors can be temporarily installed for all kinds of reasons during the entire life cycle.

Through the Optimum Use of Vehicle and Human Resources: With the option of distributed instrumentation and control managed with much less integration needed with the vehicle central system, both system experts, hardware and software can concentrate on their system performance, instead of integration issues.

“Fly-by-Wireless” Focus Areas

(1) System Engineering and Integration to reduce cables and connectors,

- Capture the true program affects for cabling from launch & manned vehicles
- Requirements that enable and integrate alternatives to wires
- Metrics that best monitor progress or lack of progress toward goals.
  (# cables, Length, # of connectors, # penetrations, overall weight/connectivity)
- Design Approach that baselines cables only when proven alternatives are shown not practical - use weight and cg until cabling can be proven needed.

(2) Provisions for modularity and accessibility in the vehicle architecture.

- **Vehicle Zones** need to be assessed for accessibility – driven by structural inspections, system assembly, failure modes and inspections, and system and environment monitoring and potential component trouble-shooting, remove & repair.
- **Vehicle Zones** need to be assessed for resource plug in points to access basic vehicle power, two-way data/commands, grounding and time (not all zones get it).
- **Centralized & De-centralized approaches** are available for measurement & control.
- **Entire life-cycle** needs to be considered in addition to schedule, performance, weight.

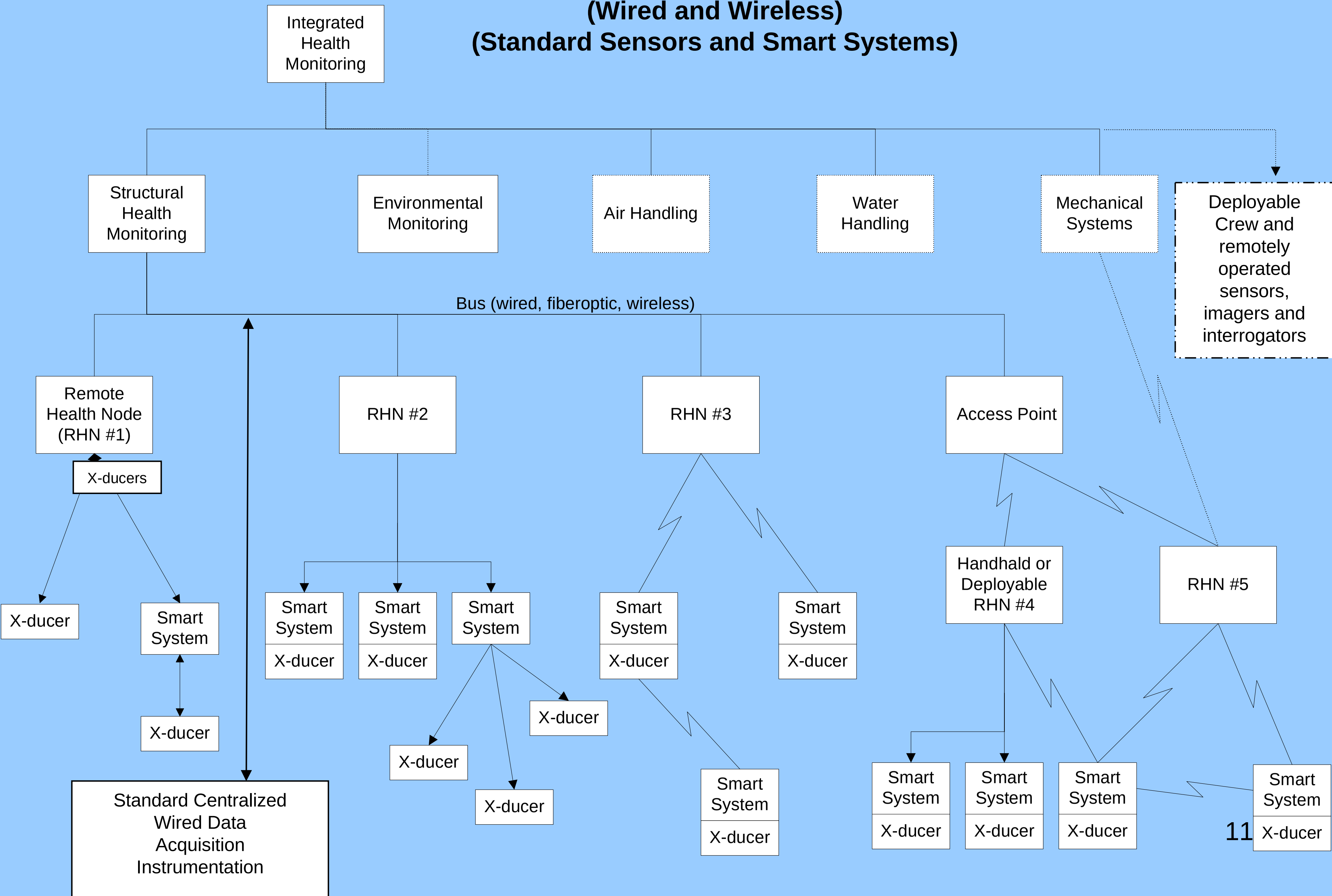
(3) Develop Alternatives to wired connectivity for the system designers and operators.

- Multi-drop Bus-based systems
- Wireless No-power sensors/sensor-tags
- Standalone Robust wireless data acquisition
- Standard interfaces & operability
- Wireless controls
- Data on power lines
- Fiber-optic
- Robust wireless radios
- Light weight coatings and shielding
- RFID for Identification, position & data

Challenge: Why Can’t Wireless connectivity be made to be as reliable as a wire??

Conceptual Hybrid SHMS Architecture for Future Space Habitats

(Centralized and Decentralized)
(Wired and Wireless)
(Standard Sensors and Smart Systems)

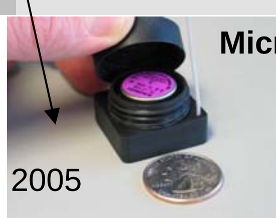


Wireless Instrumentation Systems Solving Unique Real-World Problems for Shuttle & Space Station

- **ISS Assembly**
- **ISS Structural Loads/Dynamics**
- **Shuttle Temp Monitoring**
- **Shuttle Structural Loads and Dynamics Concerns**
- **Shuttle SSME Feed-line Crack Investigation**
- **Shuttle Wing Leading Edge Impact Sensors**
- **SRMS On-Orbit Loads** at the end of the new boom, an extension of the SRMS arm.
- **Shuttle Forward Nose area dynamics during roll-out to launch pad**
- **ISS MMOD Impact/Leak Monitoring**

Evolution of Micro-WIS Systems (page 1)

System	**MicroWIS (SBIR)**	**Extended Life MicroWIS**	**MicroSGU / MicroTAU**	**Wideband MicroTAU**	**Enhanced WB MicroTAU**	**Ultra-sonic WIS (new Ph2 SBIR)**
Date Certified	1997	2001	2000/2001	2002	2005	2007 (projected)
Purpose	IVHM	Thermal Models	Cargo Loads Cert Life Extension	MPS Feedline Dynamics	Wing Leading Edge Impacts	ISS Impact/Leak Monitoring
Dimensions	1.7” dia. x 0.5”	2.7”x2.2”x1.2”	2.7”x 2.2” x 1.2”	3.0”x 2.5” x 1.5”	3.25”x2.75”x1.5	3.4” x2.5”x 1.1”
Sample Rate	Up to 1Hz	Up to 1Hz	Up to 500Hz (3 channels)	Up to 20KHz (3 channels)	Up to 20KHz (3 channels)	Up to 100KHz (10 channels)
Data Sync	No	No	Yes	Yes	Yes	Yes
Data Storage	None	2Mbytes	1Mbyte	256Mbytes	256Mbytes	1Mbyte
Data Transmit / Relay	Real-time Transmit to PC	Real-time Transmit to PC / Relay	On-demand Transmit	On-demand Transmission	On-demand Transmission	On-demand Transmission

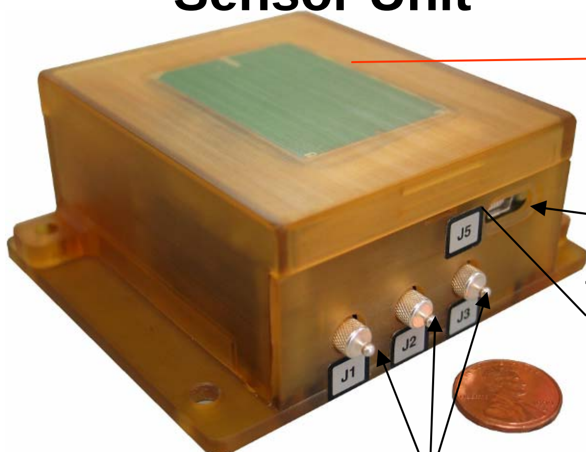


Micro-WIS XG

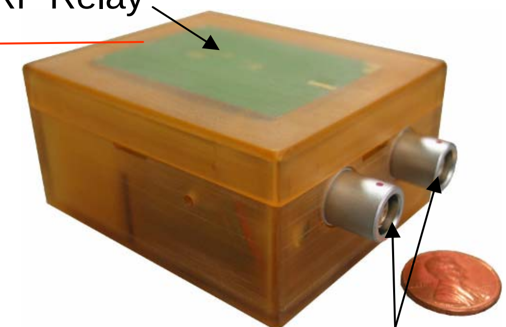
WLEIDS System Overview: GFE Hardware

Enhanced Wide-band Micro-Triaxial Accelerometer Unit (EWB Micro-TAU)

Sensor Unit



Relay Unit



Patch Antennas for RF Relay

USB Port

Temperature Channel

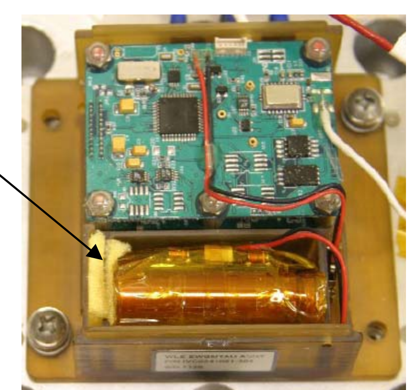
Accelerometer Channels

Relay Unit 485 Connectivity to Crew Cabin (wired)

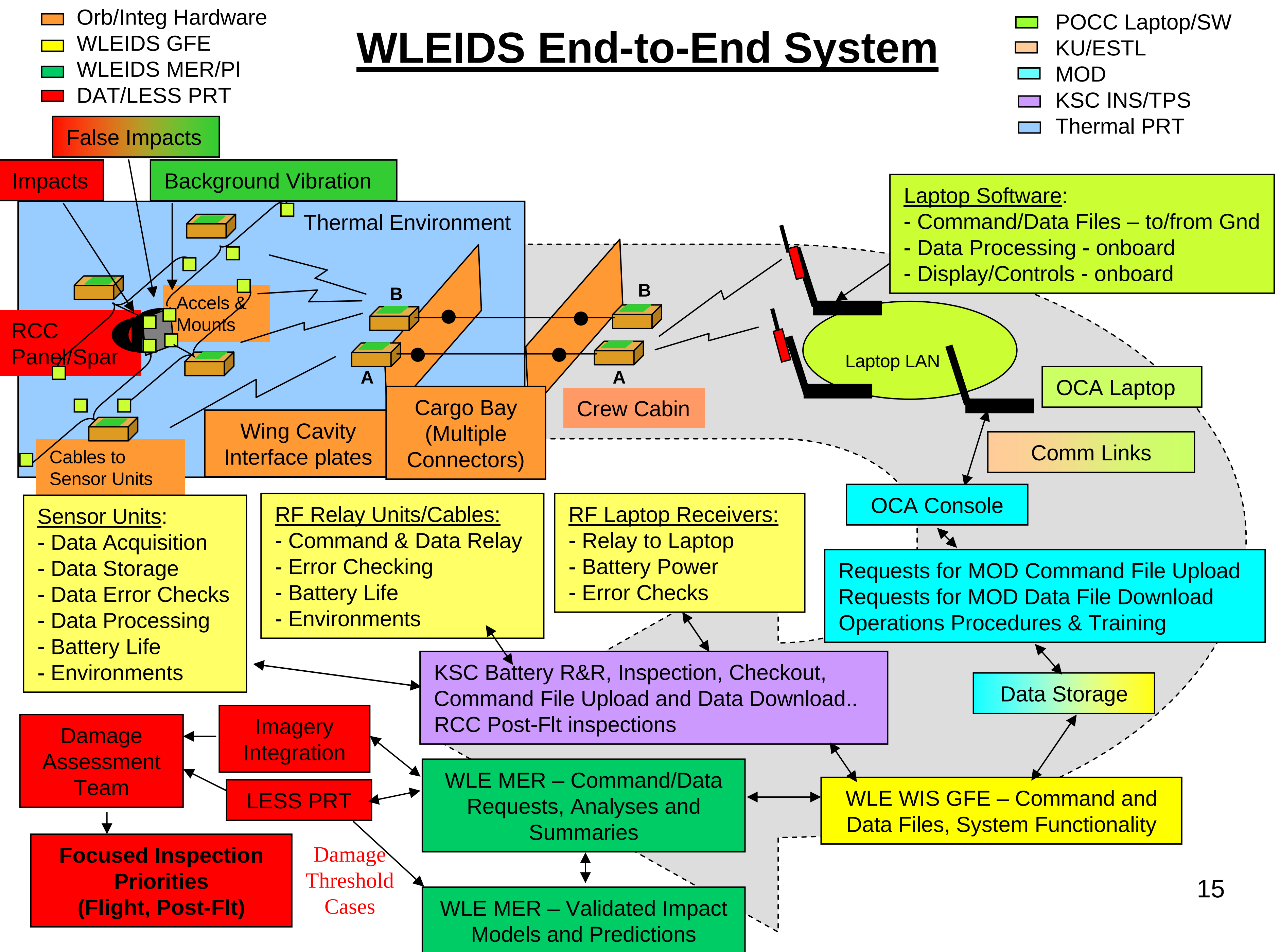
Original Plan:
Lithium BCX C-cell Battery (low temps but too hazardous)

Current Configuration:
Two L91 AA LiFeS2 cells (dies at 0 deg F)

In Work:
Add Voltage Regulator

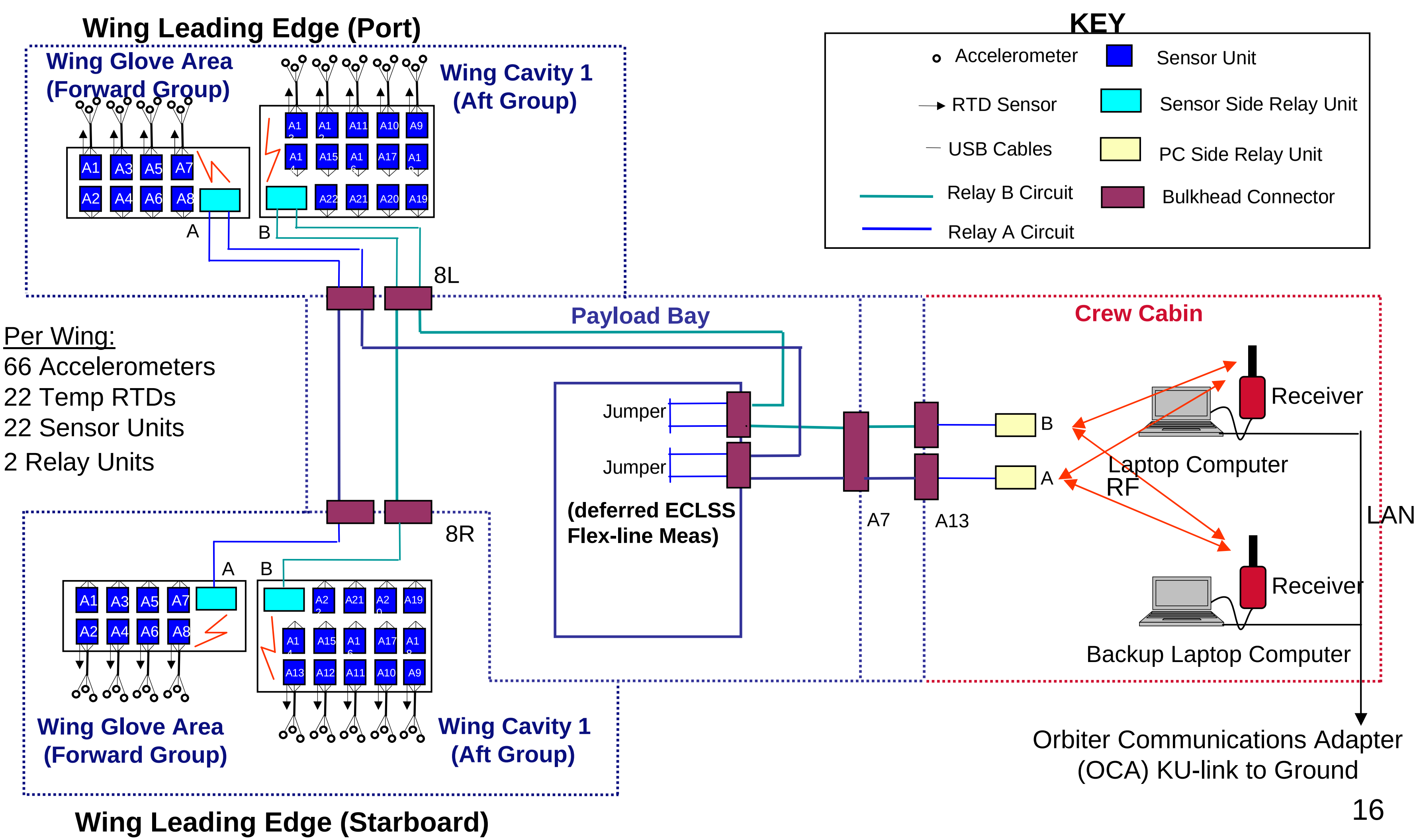


WLEIDS End-to-End System



WLEIDS System Overview: Vehicle Wiring Diagram

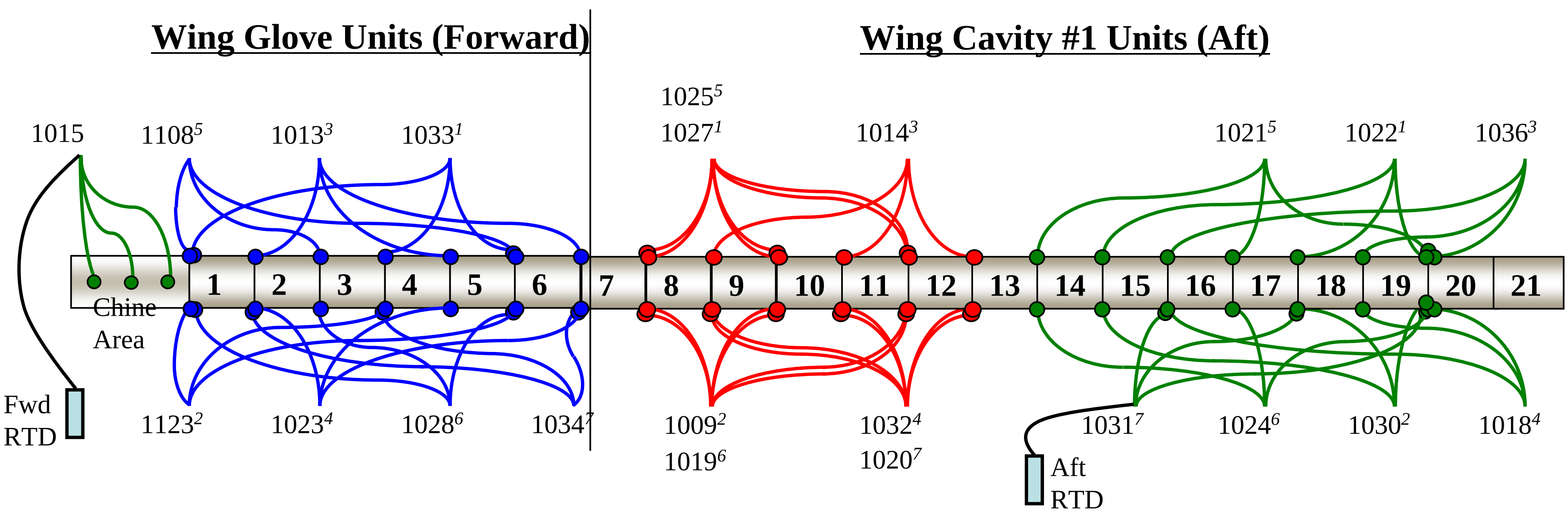
- Sensor Units can communicate with Cabin via Relay path A or B



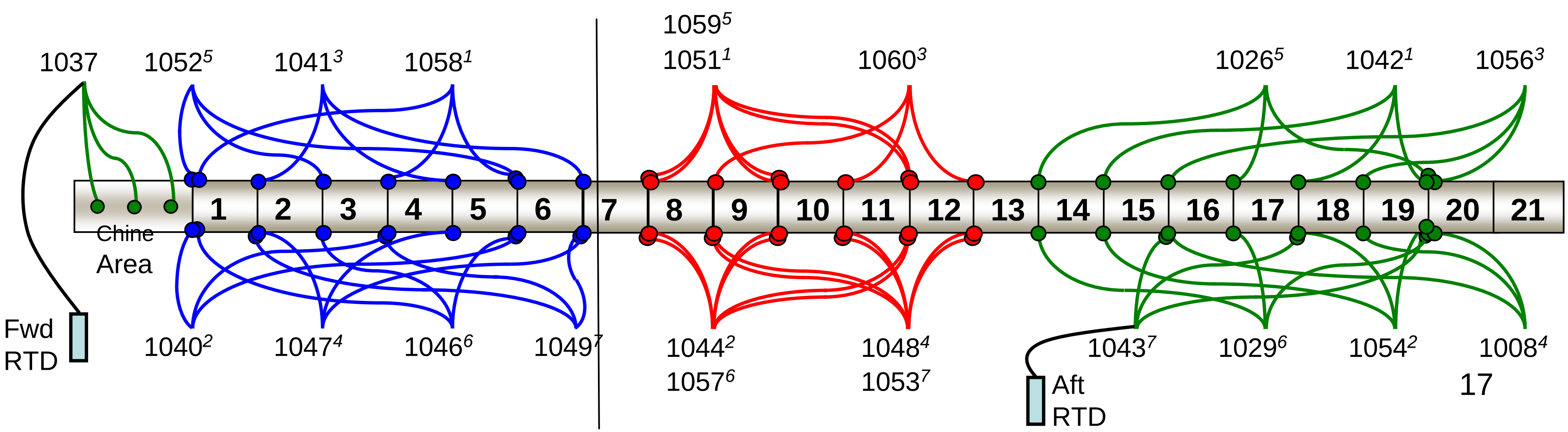
Per Wing:
66 Accelerometers
22 Temp RTDs
22 Sensor Units
2 Relay Units

Accelerometer to Sensor Unit Cross-Strapping

STS-121 Port Wing Accelerometer – Sensor Unit Configuration

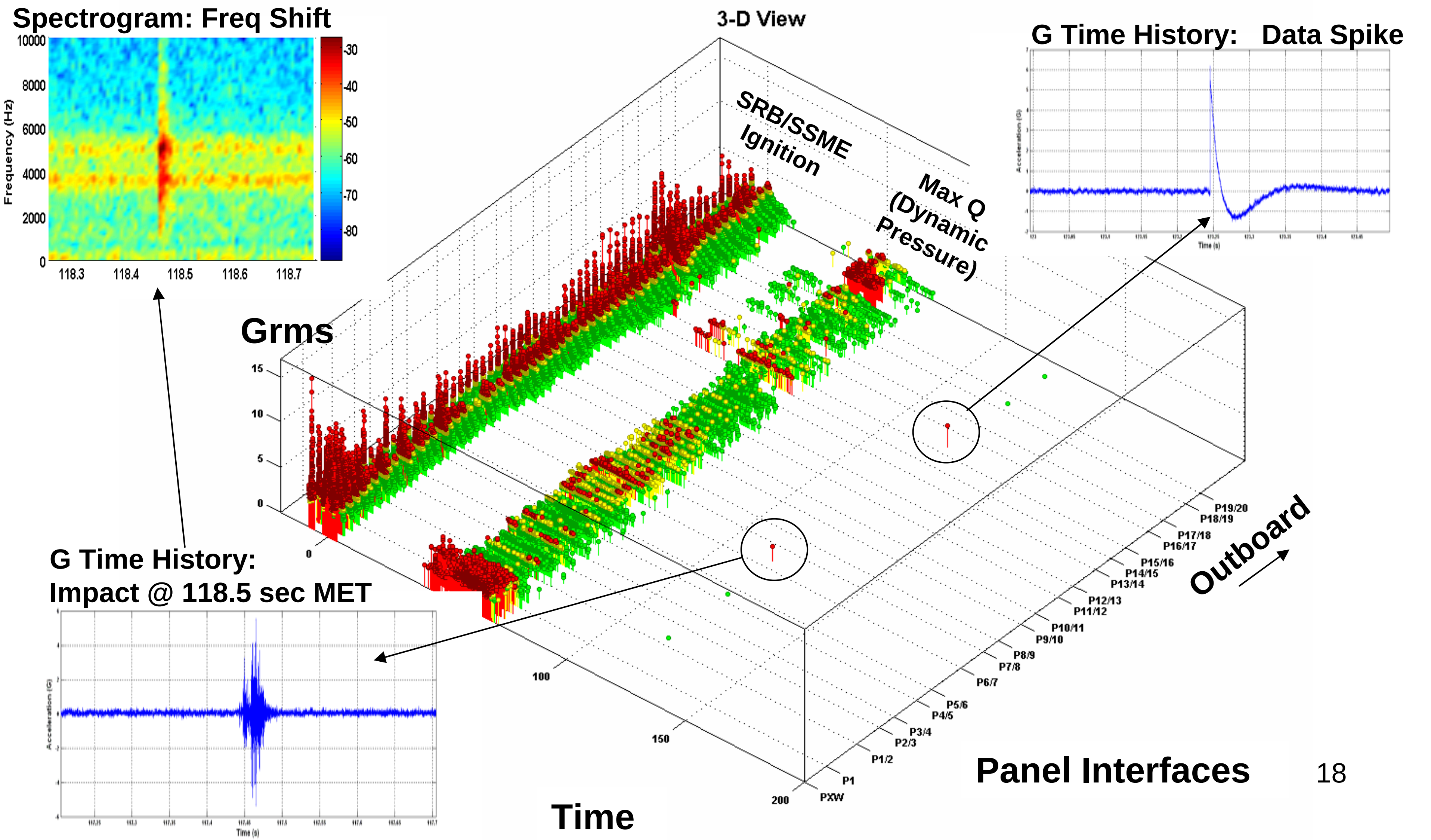


STS-121 Starboard Wing Accelerometer – Sensor Unit Configuration



STS-114 Ascent Data Analysis: Mission Tools

Half second time history downloads used to distinguish between real impact events and data anomalies



Passive (no Power) Micro-wave Sensor Tags

Current Sandia Prototype: Part of NASA Sponsored Technology Development

Interrogator/Receiver Prototype

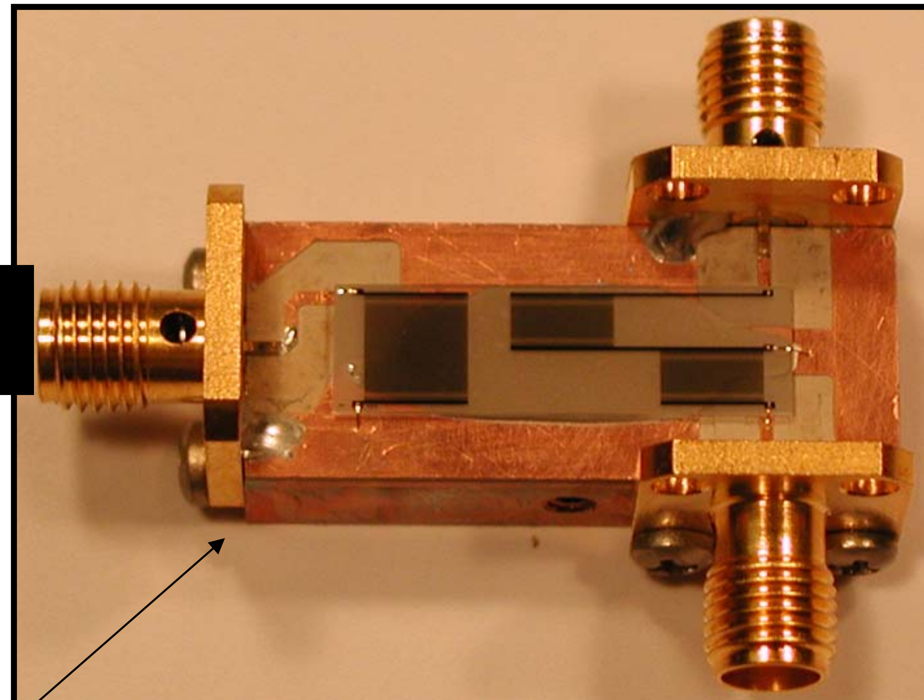
-69 MHz and 71 MHz Operating Freq

- up to 1 Megahertz sample rate

Sensor Port: - Variable Impedance Input

-Inductive pressure: 200 nanohenrys

- High impedance piezo sensor input



1 meter wire antenna

(Connector for Proto-type only)

Approximately 1” x ½” x ½”
SAW Correlators attached to Brass Base
Plastic cover (not shown)

Reference

(50 ohm)